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SPHERE DRAG TESTS IN THE VARIABLE DENSITY WIND TUNNEL

By Eastman N. Jacobs
Langley Memorial Aeronautical Laboratory

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Summary

The air forces on a twenty-centimeter sphere were measured in the Variable Density Wind Tunnel during February, 1929, after it had been rebuilt as an open-throat type. The results from tests made at widely different densities and air speeds and also on a smaller sphere, chosen to give the same range of the Reynolds Number, are given. The results are compared with those obtained in the old Variable Density Tunnel and in other tunnels in order that an estimate of the conditions of turbulence existing in the new tunnel may be formed.

The conclusions are that approximately the same drag coefficient is obtained at a given value of the Reynolds Number irrespective of what combination of the variables is used to obtaim that value of the Reynolds Number and that the turbulence of the air stream at the test section, as measured by the critical Reynolds Number of a sphere, is less for the new tunnel than for the old one.

Introduction

The sphere, because of its simplicity, is one of the objects whose characteristics have been most widely studied in hydrodynamic research. It has hydrodynamic characteristics, first discovered by Eiffel, which cause it to be of particular interest in the present connection. These are, a large scale effect occurring within a range of the Reynolds Number conveniently reached in most wind tunnels and a susceptibility to changes in its aerodynamic characteristics with changes in the turbulence of the air stream in which it is tested. Because of these characteristics there has been a striking lack of agreement between the drag measurements made on spheres in various wind tunnels.

In spite of the lack of quantitative agreement between the different investigations, all agree qualitatively as to the variation of the drag with dynamic scale. At low values of the Reynolds Number the drag coefficient is high and falls off rather abruptly as the Reynolds Number is increased, approaching a value known as the critical Reynolds Number for a sphere. In this report the range of values of the Reynolds Number throughout which the drag coefficient changes rapidly will be spoken of as the critical Reynolds Number. As the Reynolds Number is further increased the drag coefficient reaches a minimum and then increases slowly. The more or less abrupt drop in the drag coefficient, as explained by Prandtl (Reference 4), accompanies a change in the flow about the sphere from the laminar to the turbulent type. The reduction of drag is caused by the accompanying backward shift of the separation line of the flow on the surface of the sphere to a position aft of the equator, thus reducing the size of the wake and, consequently, the drag.

The conditions for which the type of flow about a sphere changes, as measured by the value of the critical Reynolds Number, depend on the characteristics of the air stream in which the sphere is tested. It has been shown that turbulence, produced by introducing wire screens in the air stream ahead of the sphere, reduces the value of the critical Reynolds Number. Because of this effect the results of tests on spheres under similar conditions in different wind tunnels and in free air or water may be used as a basis of comparison of the turbulence or flow characteristics corresponding to each test. Attention must be called to the fact, however, that turbulence is not the only factor affecting the sphere drag and the value of the critical Reynolds Number. Bacon and Reid have shown, for example, that even very fine protuberances and support wires, on certain parts of the surface of a sphere have a very large effect on its drag characteristics (Reference 2). The effect of such factors as degree of surface polish, static pressure or velocity gradient in the direction of the air stream, and the effect of tunnel walls, is not known.

In using a sphere as a turbulence indicator, it should be remembered that the turbulence of an air stream cannot be expressed simply, because the scale or grain of the turbulence is important as well as the intensity. In this connection, it is interesting to consider the relationship of turbulence to temperature; in fact, turbulence is a means of converting the general motion into the more random motion which manifests itself as a temperature rise. The intensity of turbulence might then be expressed as a temperature rise, but the character of the turbulence might be anything between long period velocity fluctuations on one hand and a temperature rise on the other, and it would not be reasonable to expect these two to produce the same aerodynamic effect. The effect of a temperature rise on the drag of a sphere in the region of the critical Reynolds Number may be predicted by considering that the temperature rise will increase the viscosity and thus reduce the Reynolds Number and increases the drag. Turbulence produced by a wire screen has the opposite effect, reducing the drag as a result of the effect on the value of the critical Reynolds Number.

The present investigation was originally undertaken with the object of comparing the turbulence in the new and old Variable Density Tunnels. It also afforded an opportunity to investigate another question which has frequently arisen: Will the aerodynamic characteristics of bodies as measured in the Variable Density Wind Tunnel agree at a given value of the Reynolds Number when it is obtained in different ways? For these tests it was possible to measure the drag of the sphere at air speeds of approximately one-quarter and one-half normal as well as at the normal speed. By varying the air density inversely as the speed approximately the same Reynolds Numbers could be obtained in different ways.

Tests and Apparatus

The original Variable Density Wind Tunnel and the principles upon which it operates are fully described in Reference 1. The tunnel has since been rebuilt, the principal changes being the adoption of a Prandtl type entrance cone with the honeycomb at the large end, and the change to an open throat type, as shown in Figure 1. The tunnel propeller is regularly driven by a synchronous motor which gives an air speed of about 63 feet per second, but, for these tests, arrangements were made for driving the propeller by a belt from a 50 hp direct current motor, in order that the air speed might be varied.

The spheres used in the present tests were the same hardwood spheres used in the previous tests in the old Variable Density Tunnel and in the atmospheric wind tunnel (Reference 2), refinished to give a polished surface. The 20-centimeter sphere was mounted on the balance in the center of the air stream, as indicated in Figure 1, by means of a steel rod 3/4 in. in diameter, projecting into the sphere from behind. The 15-centimeter sphere was similarly supported by a $\frac{1}{2}$-inch rod. The rod was connected to the balance by a streamlined wooden strut. Later, for the support drag measurements, the sphere was fixed with respect to the tunnel walls by wires and the steel rod sawed off just behind the sphere.

The drag of the 20-centimeter sphere was measured at several air densities between one-quarter and four times the normal atmospheric density with the normal air speed. The auxiliary motor was then connected to the propeller and a series of drag measurements obtained at approximately one-half normal speed with different densities between three-quarters and six atmospheres. Another series of drag measurements was obtained at approximately one-quarter normal air speed with different densities between two and eight atmospheres. Similar sets of drag measurements were made to obtain the tare drag variation with Reynolds Number. Drag measurements for the 15-centimeter sphere were made only at normal speed.

The dynamic pressure was found from a measurement of the static pressure difference between the return passage of the tunnel and the test section. This had been compared previously with the dynamic pressure in the test section as measured by a Pitot-static tube without the sphere in place. A static pressure survey was run along the axis of the tunnel to provide data for correcting the sphere drag for horizontal buoyancy. This correction as given in Reference 3 has been applied to the results.

Results and Discussion

The results are presented by means of two sets of curves. In Figure 2 the drag coefficients are plotted against Reynolds Number, the results of the tests on the larger sphere at the different speeds and on the smaller sphere, being represented by different types of plotted points. In Figure 3 the curve of drag coefficient against Reynolds Number is given together with curves representing the results of other investigations for comparison.

It will be seen from Figure 2 that the drag coefficient is the same, within the limit of accuracy of the experiments, at a given value of the Reynolds Number irrespective of what combination of velocity, kinematic viscosity and sphere size is used to give that Reynolds Number. This is a significant conclusion in view of the difficulty of obtaining agreement between the drag coefficients for a sphere from tests at a given Reynolds Number in different wind tunnels. From this result it may be inferred that the error resulting from scale effect in model testing is totally eliminated in the Variable Density Wind Tunnel, and that any error remaining between the results of model and flight tests must be attributed either to lack of geometric similarity of model and full scale object, including the supporting mechanism , or to lack of similarity of the air streams. The latter difficulty will be always inherent in wind tunnel testing and would apply with equal force to any other wind tunnel even though the desired Reynolds Number were obtained by testing full size models at full speed.

In Figure 3 the results from the Variable Density Wind Tunnel are compared with the results from other sphere tests. The agreement between the drag curves is better than that usually found when the results of sphere tests from different sources are compared. It is evident that the agreement between the curves is good except for a displacement resulting from different values of the critical Reynolds Number. Since the curves all represent the results of wind tunnel tests on spheres when similarly supported, the displacement must, to a large extent, be attributed to differences in the structure of the different air streams in which the spheres were tested.

These curves indicate that the Göttingen wind tunnel has the least turbulent air stream and that the N.A.C.A. atmospheric wind tunnel, without the fine honeycomb which is ordinarily used ahead of the test section, is next in order of turbulence. The turbulence was increased, as indicated by the curve marked "honeycomb in place," when the tests were repeated after installing the honeycomb. The old Variable Density Wind Tunnel apparently had an excessively turbulent air stream, as the indicated value of the critical Reynolds Number was only about half of that indicated by the present tests in the rebuilt tunnel. The excellent agreement between the curve from the atmospheric wind tunnel and the one giving the results of the present investigation indicates that the two tunnels are about the same as regards turbulence. Assuming that the atmospheric wind tunnel with the honeycomb in place is fairly representative of other atmospheric wind tunnels, it may be concluded that the degree of turbulence of the air stream in the rebuilt Variable Density Tunnel is about the same as most other tunnels, instead of very much greater as before the tunnel was rebuilt, and that in the future better agreement may be expected between the results of low scale tests in the Variable Density Tunnel and in other wind tunnels.

Conclusions

This investigation indicates that, within the accuracy of the experiments, the same drag coefficient is obtained at a given value of the Reynolds Number, irrespective of what combination of the variables, length, density and velocity, is used to obtain that value of the Reynolds Number.

The turbulence of the air stream, as measured by the critical Reynolds Number of a sphere, is less for the new tunnel than for the old one.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., May 27, 1929.

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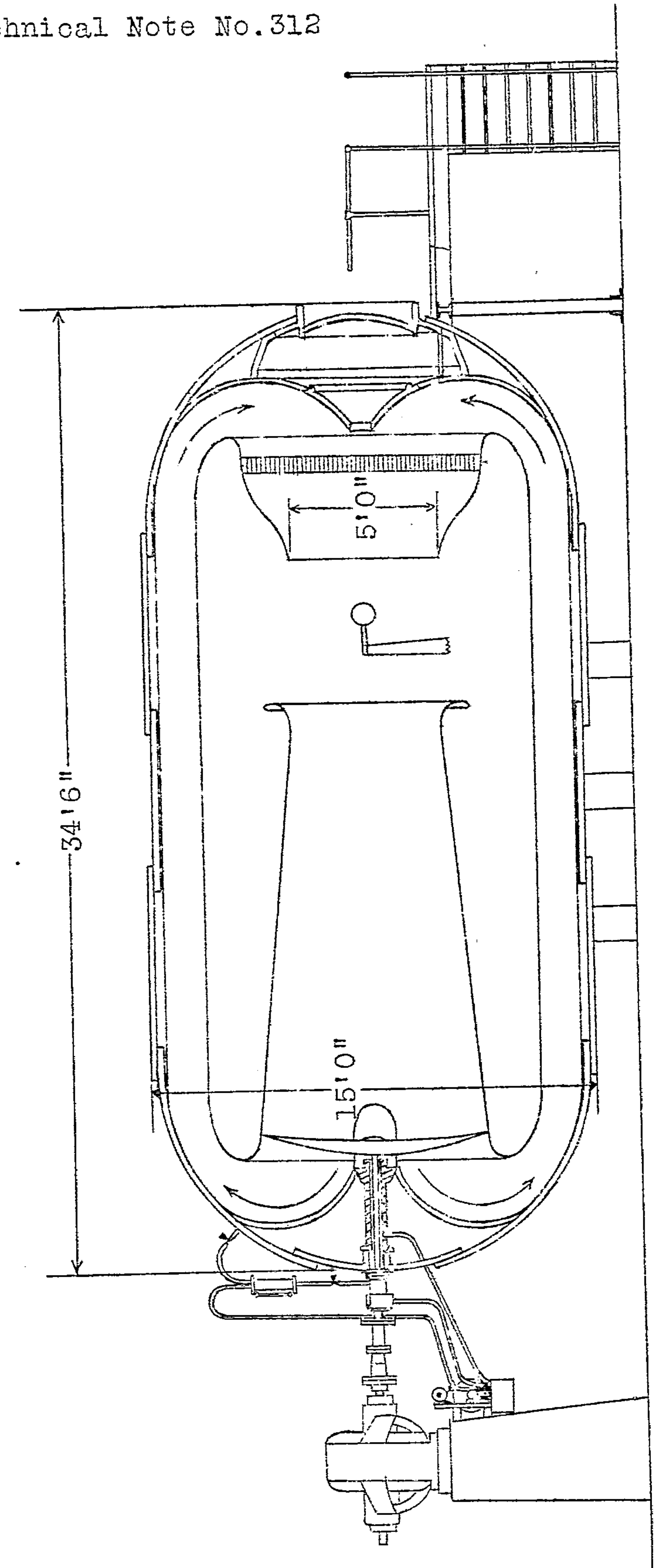
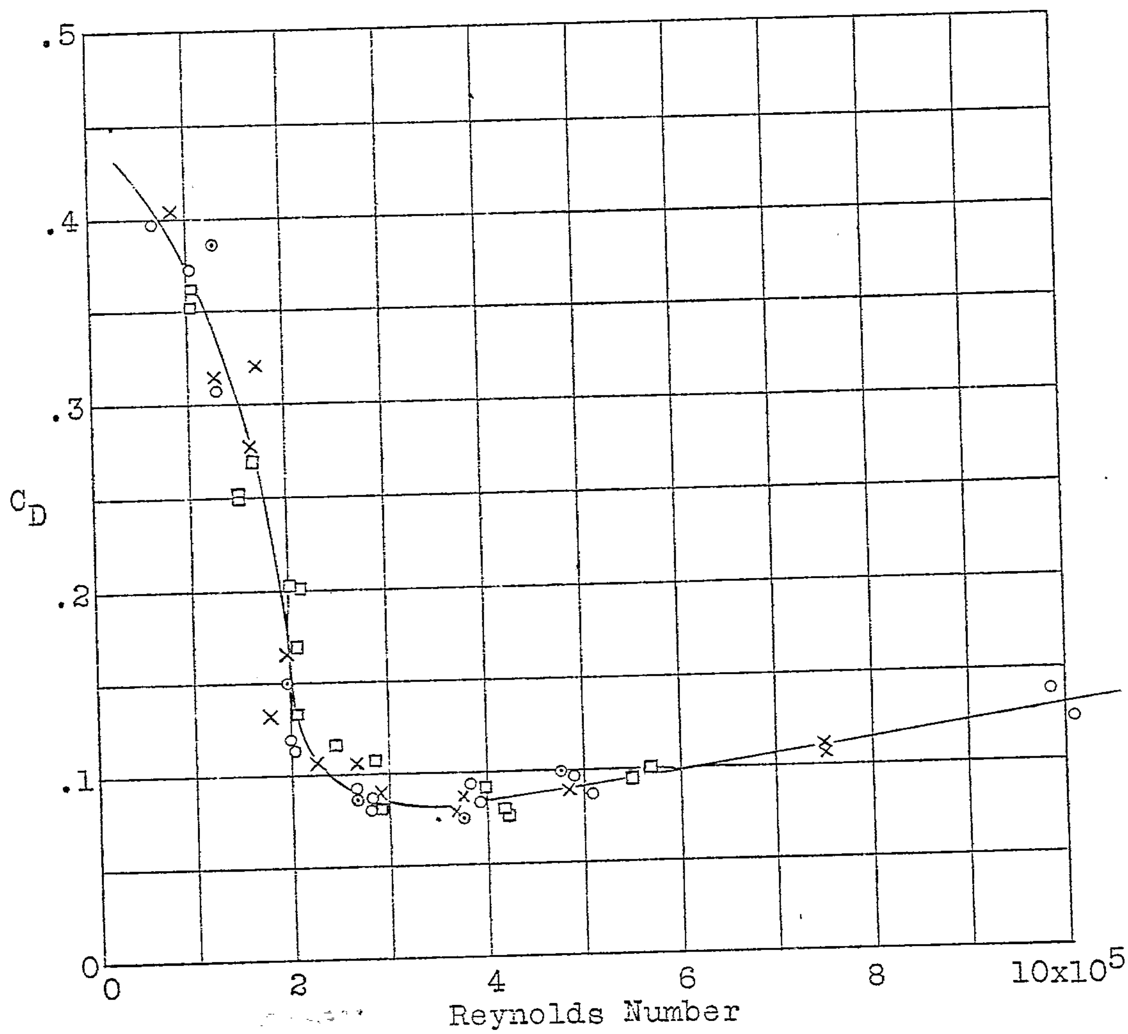


Fig.1 Section of tunnel showing sphere mounting.



○ 20cm sphere. Air speed normal (65 ft./sec.)

× 20cm " " " about one half.

⊙ 20cm " " " about one quarter.

□ 15cm " " " normal.

Fig.2 Sphere drag coefficient,

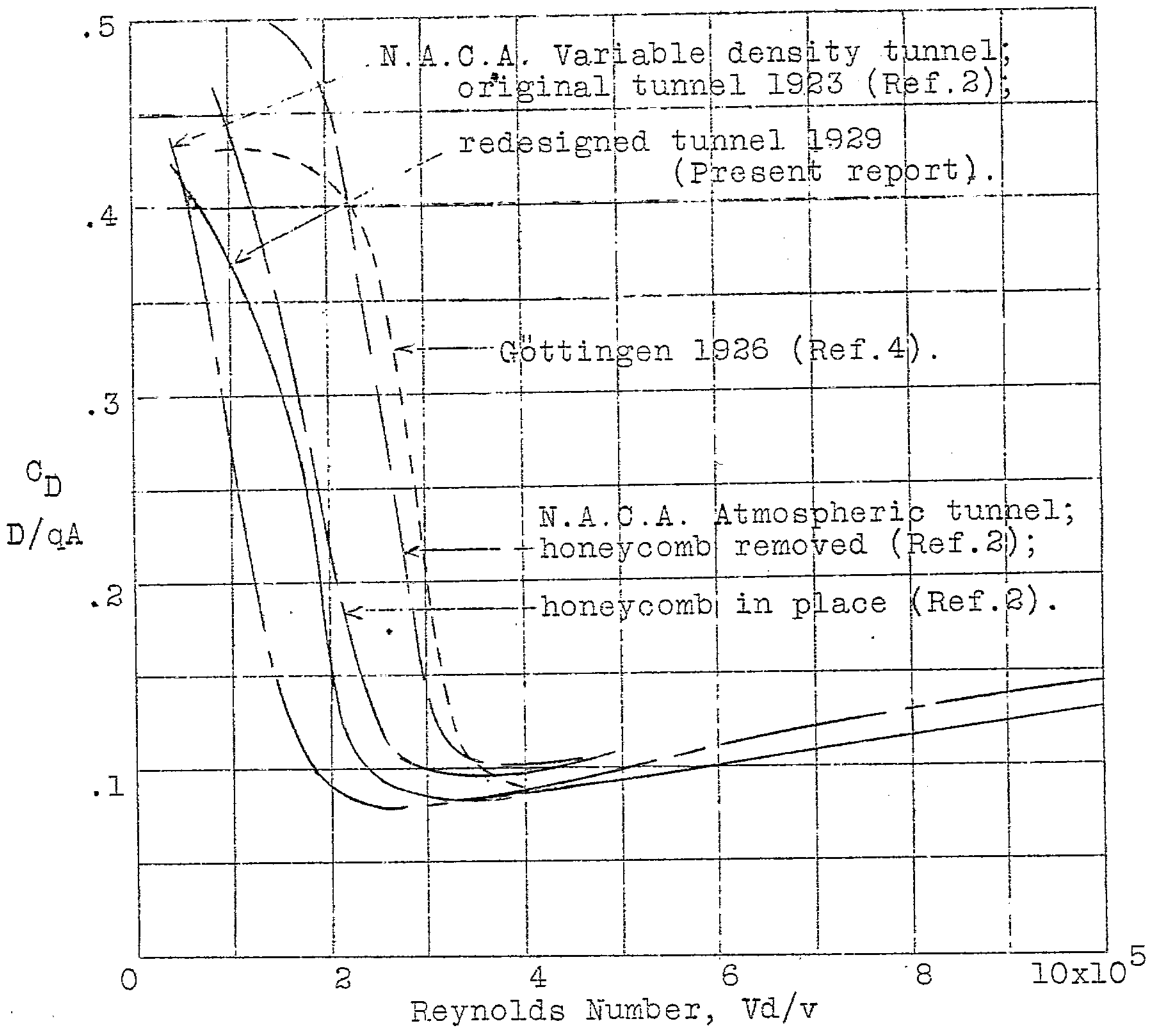


Fig. 3 Comparison of sphere tests.